

## UPDATE ON UNDERWATER NOISE AND PILE DRIVING




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## Recent Fish-Kills

### California

San Francisco-Oakland Bay  
Benicia-Martinez Bridge  
8 ft dia. hollow steel piles  
Impact hammer 550-1700 Kilojoules

### Vancouver, BC

36" dia. hollow steel  
piles  
Impact hammer

### Puget Sound

Mukilteo Ferry Terminal - 2001  
Winslow Ferry Terminal - 2002  
Port of Seattle (2 reports) - 2003  
Bremerton Ferry Terminal - 2003  
24-30" dia. hollow steel piles  
Impact hammer

Sturgeon  
Plainfin midshipmen  
Tom cod  
Salmonids  
Herring  
Anchovies  
Sardines  
Smelt  
Surfperches - 3 spp.  
Striped bass  
Rockfishes




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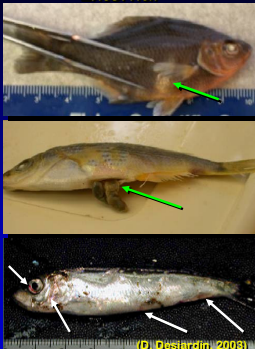
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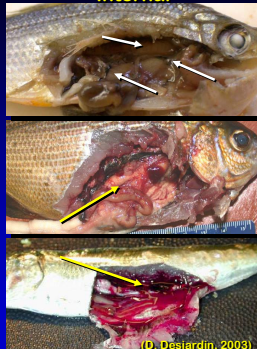
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## Barotrauma

### External



### Internal




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## The "Gong Show" Theory

(with my apologies to Dr. Hastings)

- Sound pressure wave is the "hammer"
- Swimbladder is the "gong"
  - Vibrates at resonant frequency
    - ~ 800 Hz
  - Expands and contracts
- Sharper and louder sounds increase amplitude of vibration
- Strains swimbladder and puts pressure on internal organs

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## Acoustics Basics

- Definition of Sound: A small perturbation in a fluid from ambient conditions through which energy is transferred away from a sound source by progressive fluctuations of pressure (or sound waves).
- Can be expressed in terms of Pressure (e.g., PSI, Pascals, Bars, etc.)
- Conveniently expressed in terms of decibels (dB)

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## Acoustics Basics

- Decibel to Describe Sound
  - A logarithmic measure of the sound strength
  - Base 10 Log function of the ratio of the pressure fluctuation to a reference pressure.
- Calculation of Sound Pressure Level (SPL)
 
$$\text{SPL} = 10 \log (p/p_{\text{ref}})^2 \quad \text{or} \quad \text{SPL} = 20 \log (p/p_{\text{ref}})$$

where  $p_{\text{ref}}$  is the reference pressure:

  - $p_{\text{ref}} = 20 \mu\text{Pa}$ , for air
  - $p_{\text{ref}} = 1 \mu\text{Pa}$ , for water

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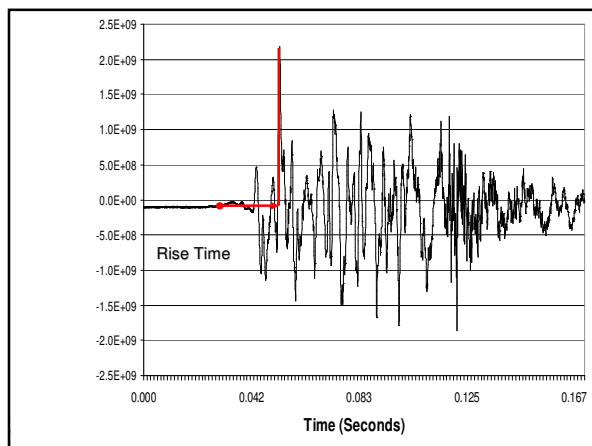
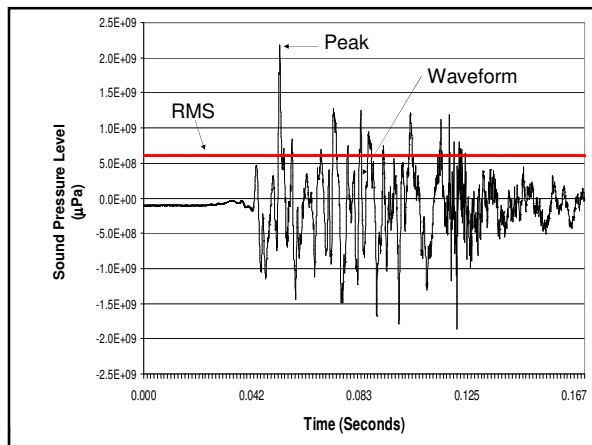
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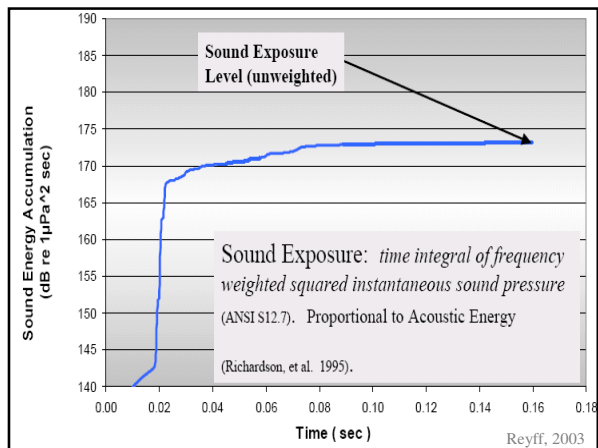
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## Acoustics Basics

- Peak Pressure
  - Max absolute value instantaneous pressure -  $\mu\text{Pa}$
- Root Mean Square – RMS
  - Quadratic mean of the pressure -  $\mu\text{Pa}$
- Rise Time
  - Time between zero (background) and peak - seconds
- Sound Exposure Level - SEL
  - Time-Integrated Pressure Squared -  $\mu\text{Pa}^2\cdot\text{sec}$






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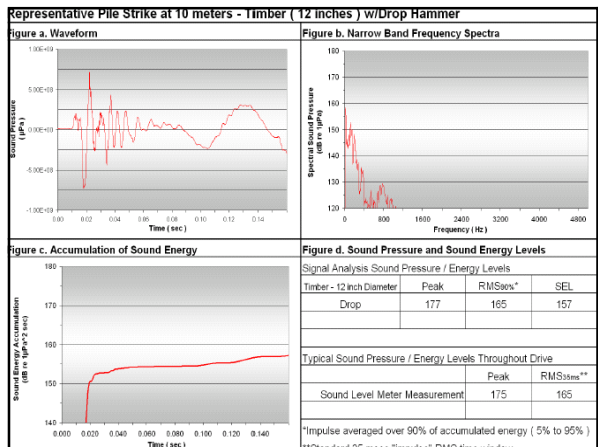
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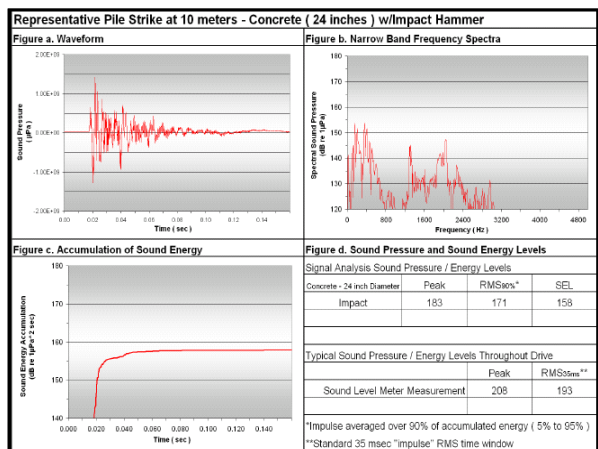
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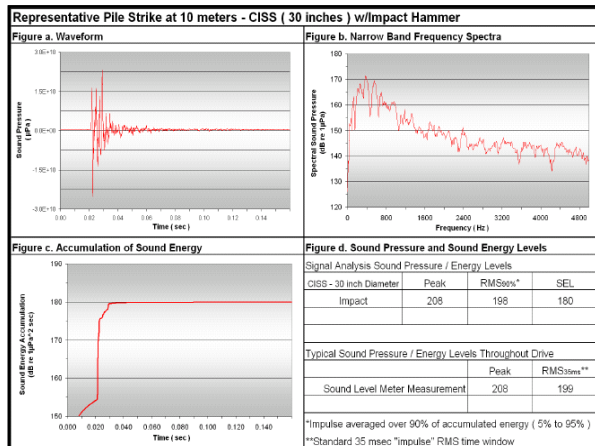
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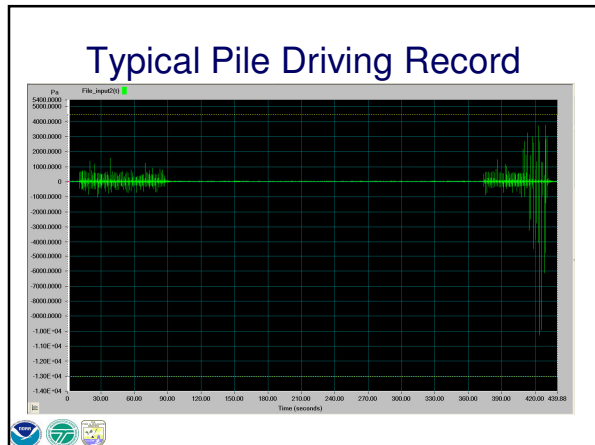
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**New Criteria for Underwater Noise and Fish**

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## Fisheries Hydroacoustic Working Group (FHWG)

- *Federal Highway Administration*
- *National Marine Fisheries Service*
- *US Fish and Wildlife Service*
- *State DOTs (Caltrans, WSDOT, ODOT)*
- *Other resource agencies and technical experts*

- Formed in 2004
- Contracted Dr. Mardi Hastings and Dr. Art Popper
- Worked to establish interim thresholds
- "Effects of Sound on Fish" (Hastings and Popper 2005)




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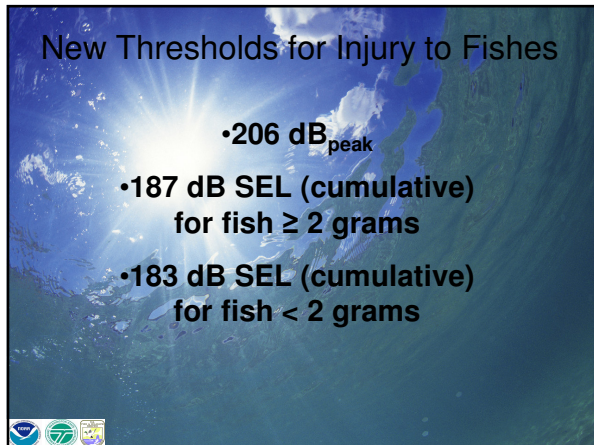
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## New Thresholds for Injury to Fishes

- **206 dB<sub>peak</sub>**
- **187 dB SEL (cumulative)  
for fish ≥ 2 grams**
- **183 dB SEL (cumulative)  
for fish < 2 grams**




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## Determining How Many Fish will be Affected




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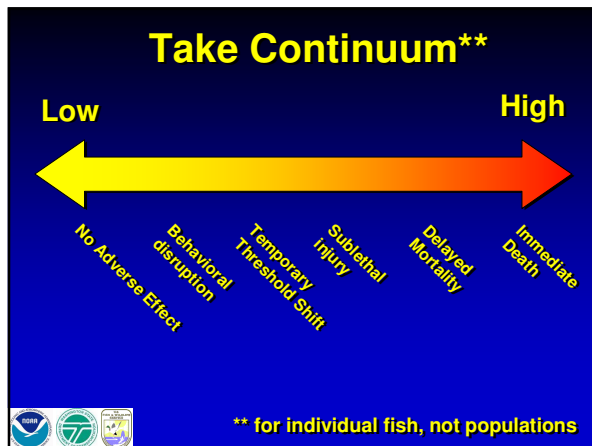
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### How do we use these criteria?

1. Calculate the distance from pile where effects are expected
2. Calculate area affected
3. If data on fish density, calculate number of fishes affected

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### Transmission Loss (TL)

- Sound attenuates with distance from source
  - Geometrical Spreading
  - Absorption/Scattering
- Practical) Spreading Loss Model
  - $TL(dB) = 15 \log (R_1/R_0) + \alpha R$
- Where:
  - TL = Transmission Loss in dB
  - $R_1$  = Range
  - $R_0$  = Range of known sound level
  - $\alpha R$  = Linear Absorption and Scattering Loss (alpha value not agreed upon so ignore for now)

$TL(dB) = 15 \log (R_1/R_0)$

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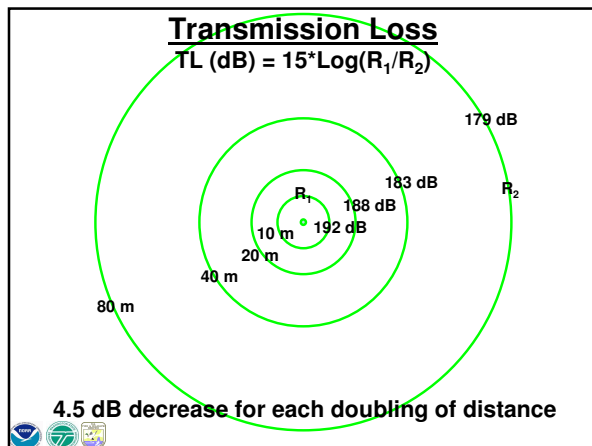
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### Computing Received SEL (Exposure)

- Depends upon:
  - Number of pile strikes
  - Distance from pile (transmission loss)
  - Behavior of fish
  - Tissue recovery
- Cumulative SEL = Single Strike SEL +  $10\log(\# \text{ Strikes})$
- Example: Cum. SEL =  $180 \text{ dB}_{SEL} + 10\log(200 \text{ strikes}) = 180 \text{ dB} + 23 \text{ dB} = 203 \text{ dB}_{SEL} \text{ (cumulative)}$

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## Underwater Sound Criteria

Received levels

10 meters – no biological significance

Independent of distance

Applicable to all fishes

ESA and EFH

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## Underwater Sound Criteria (cont'd)

Onset of Injury expected if either:

- Cumulative SEL – Size dependent
  - Fishes  $\geq 2$  grams = 187 dB (re:  $1 \mu\text{Pa}^2 \cdot \text{sec}$ )
  - Fishes  $< 2$  grams = 183 dB (re:  $1 \mu\text{Pa}^2 \cdot \text{sec}$ )
- Peak pressure  $\geq 206$  dB (re:  $1 \mu\text{Pa}$ )

Adverse behavioral disruption expected if:

- RMS pressure  $\geq 150$  dB (re:  $1 \mu\text{Pa}$ )




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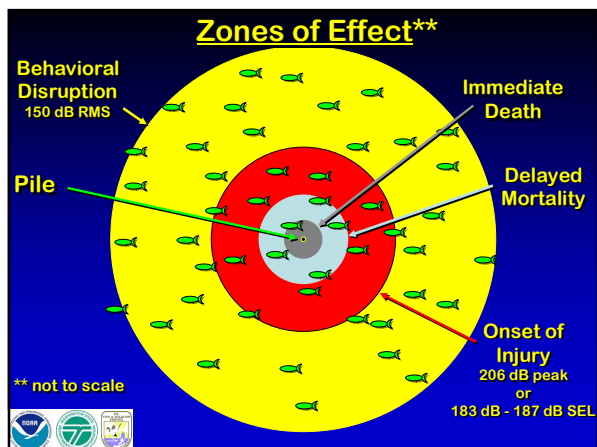
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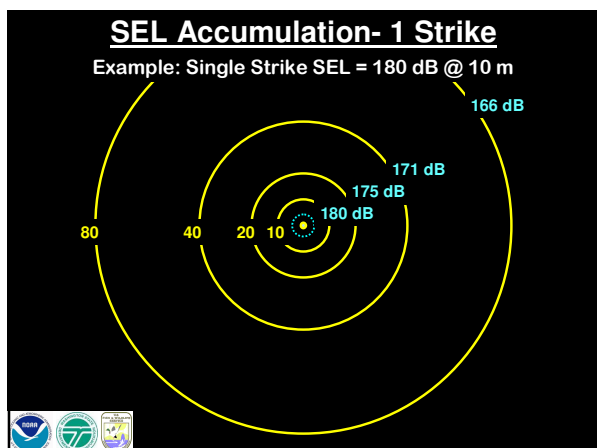
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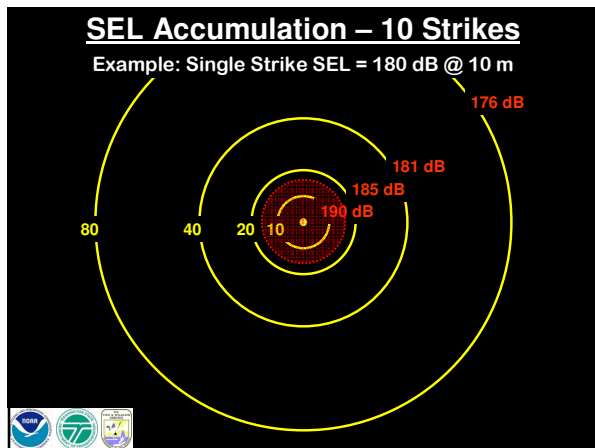
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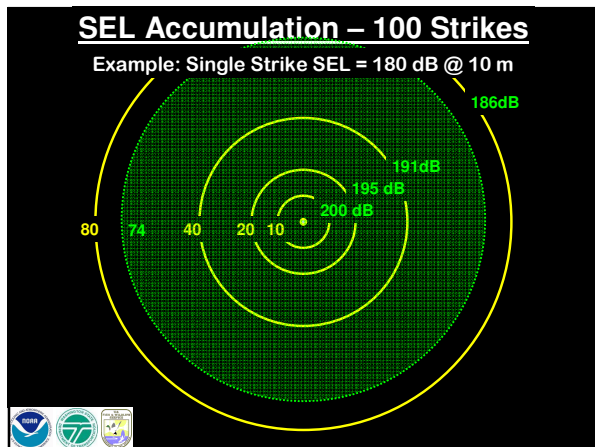
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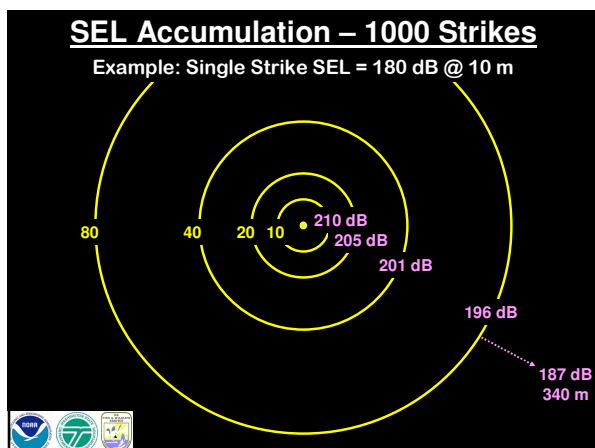
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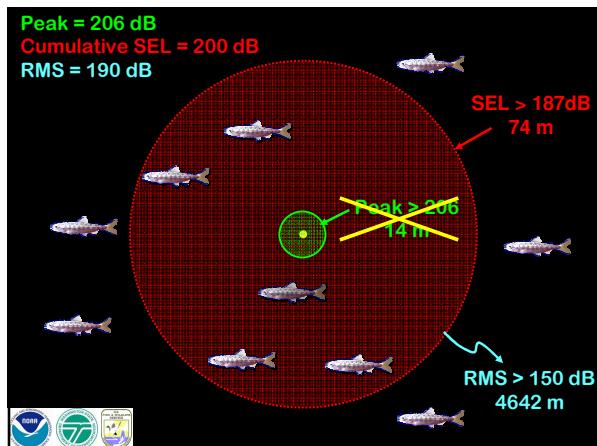
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### Transmission Loss (TL)

$TL(dB) = 15 \text{ Log } (R_1/R_0)$

### Distance to Threshold

$R_1 = R_0 \cdot 10^{(TL/15)}$

Where: TL = transmission loss to meet threshold  
= estimate at  $R_0$  - threshold

e.g., if RMS = 180 at 10 m  
TL = 180 - 150 = 30 dB

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### NMFS Spreadsheet

### Calculates Distances to Thresholds

[NMFS Pile Driving Calculations 07-28-2008.xls](#)

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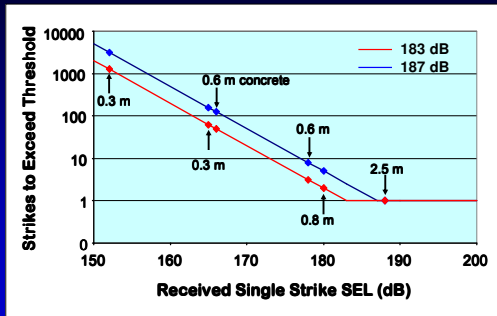
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### Strikes to Exceed Cumulative SEL Thresholds

$$\# \text{ Strikes} = 10^{((\text{Threshold}-\text{SEL}_{ss})/10)}$$




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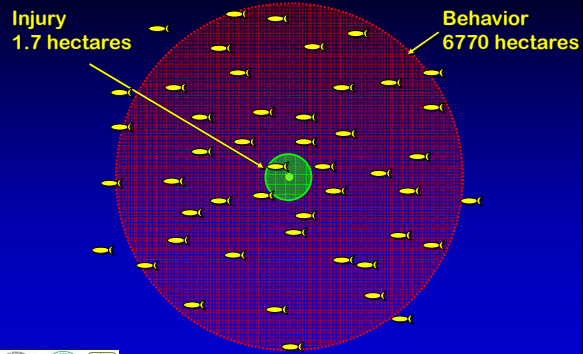
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$$\text{Affected Area} = \pi R_1^2$$




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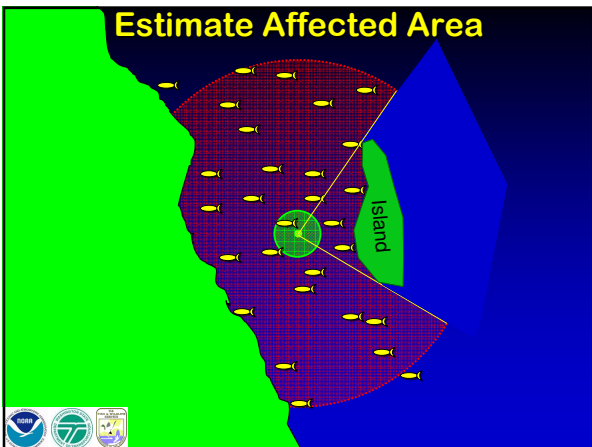
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### Estimate Affected Area




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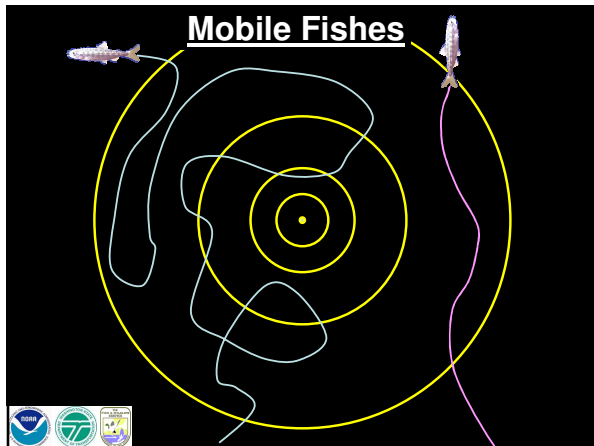
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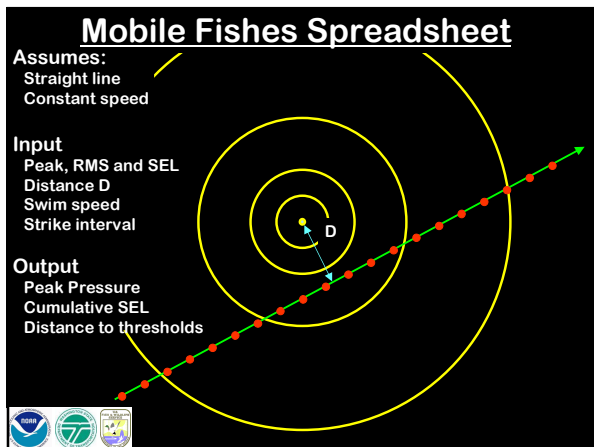
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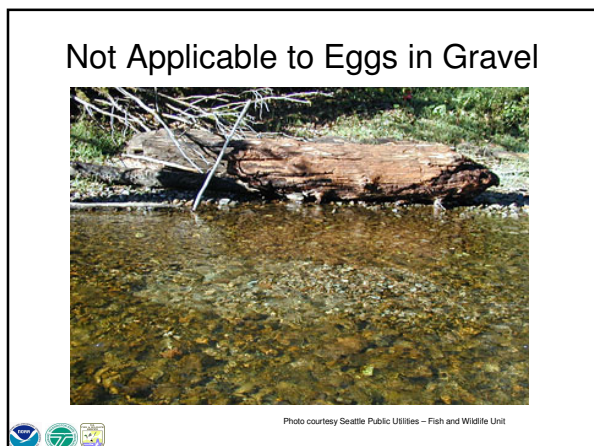
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## Other Species?

- **Marine Mammals?**
  - 180 dB RMS (Orcas)
  - 190 dB RMS (seals/sea lions)
- **Marbled Murrelets (marine diving birds)**
  - 180 dB Peak
  - 150 dB RMS



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## What Does This Mean for WSDOT Projects?



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## What this means for WSDOT projects

- How do I know how many strikes?
- How do I know what are typical sound levels?
- What are some of the differences with pile diameters/types?



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## Calculating SEL

Location	Pile Diameter (inches)	Number of Piles	Number of Strikes/Pile	Number of Strikes/Day
Cape Disappointment Boat Launch Facility	12	1	191 <sup>2</sup>	191 <sup>2</sup>
			147 - 271 <sup>2</sup>	816 <sup>2</sup>
SR 240 - Yakima River	16	2	183 - 419	602
		3	404 - 460	1,295
Bainbridge Island Ferry Terminal	24	2	534 - 552	1,086
		3	432 - 639	1,578
Eagle Harbor Maintenance Facility	24	7	11 - 30	134
Friday Harbor Ferry Terminal	24	1	326	326
		1	477	477
		1	203	203
		1	130	130
		1	271	649
		1	378	
	30	1	78	78
		1	114	114
Anacortes Ferry Terminal	36	2	323 - 442	765
		4	341 - 675	2,494
Mukilteo Test Pile Project	36	4	73 - 227	682




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## What this means for WSDOT projects

Pile Diameter	dB PEAK	dB RMS	dB SEL
12-inch Steel	203 - 208	188 - 191	171 - 175
24-inch Steel	204 - 211	190 - 198	201 - 206
30-inch Steel	212 - 215	195 - 196	186 - 187
36-inch Steel	210 - 214	197 - 201	182 - 186
Wood Piles	180	170	160
24-inch Concrete Piles	184 - 192	173 - 176	163 - 174
H- Piles	190	165 - 175	155

\* - All values are 10 meters from the pile. Wood, Concrete and H-pile data from Pile Driving Compendium




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## UNDERWATER MINIMIZATION STRATEGIES FOR PILE DRIVING




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## MINIMIZATION STRATEGIES

- Bubble Curtain – 0 dB to 23 dB reduction




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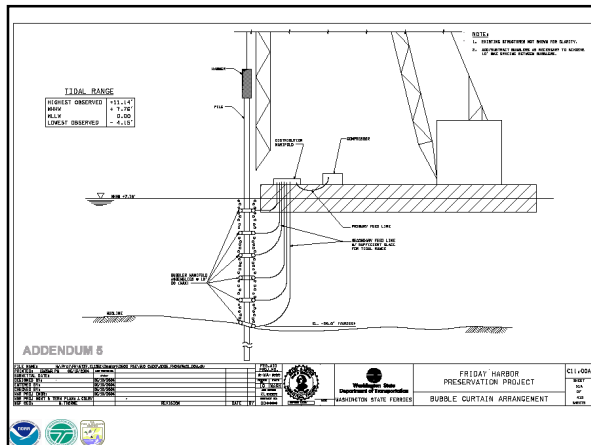
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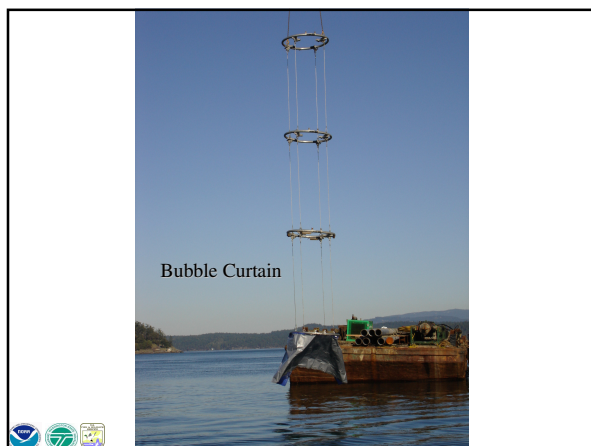
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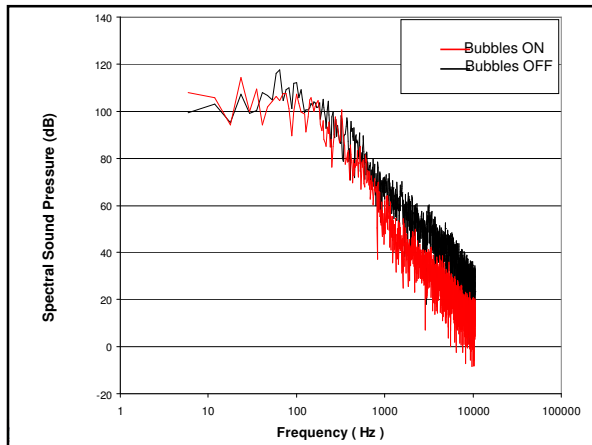
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## MINIMIZATION

- Bubble Curtain
- Sleeves – 10 dB to 23 dB reduction  
Cost slightly higher than single ring bubble curtain




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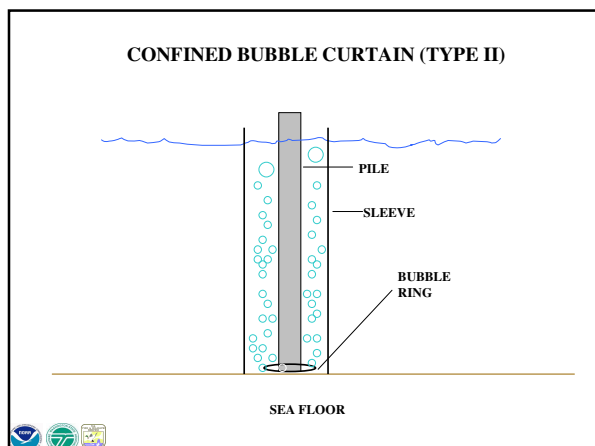
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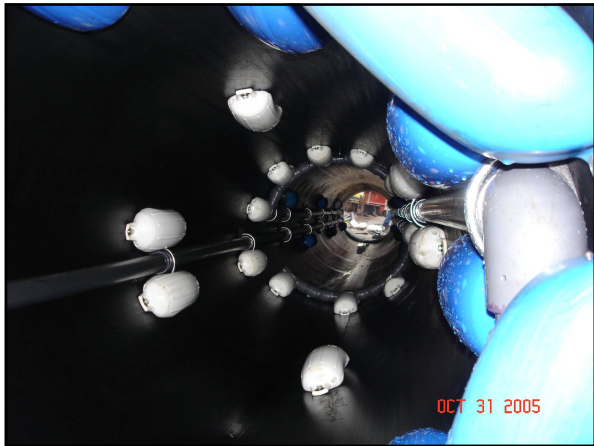
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## MINIMIZATION

- Bubble Curtain
- Sleeves
- Pile Cushions



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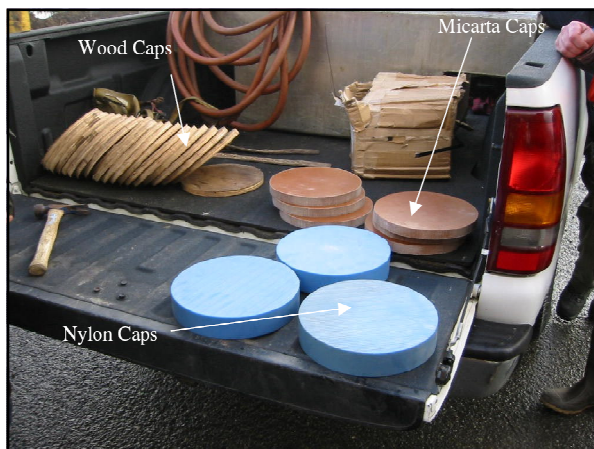
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## MINIMIZATION

- Bubble Curtain
- Sleeves
- Pile Caps
- Dry Cofferdams
- Timing
- Driving above the MHHW line
- Using Vibratory Hammers




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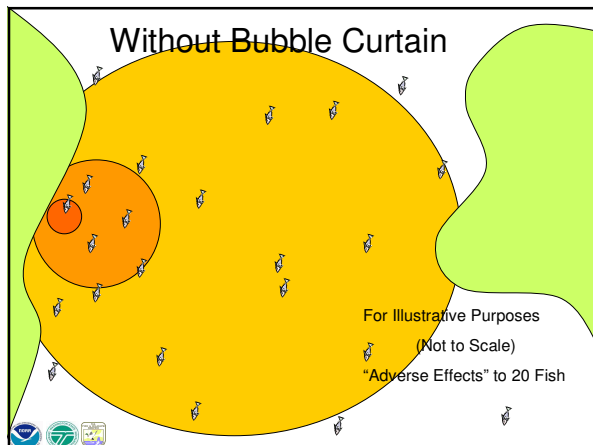
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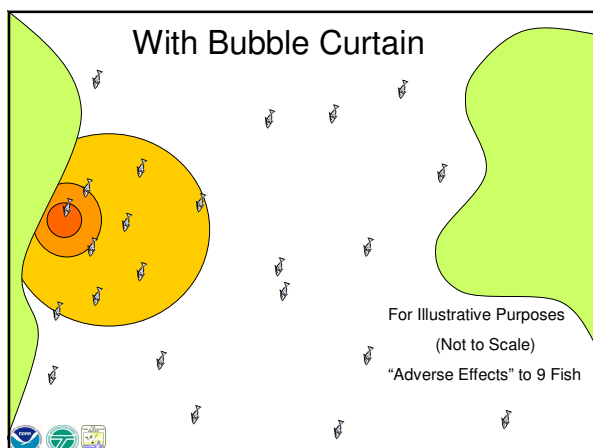
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## WHAT'S NEXT

- **Research**

- NCHRP research ongoing looking at effects on fish
- WSDOT Research \$ and FHWA Pooled Fund to look at modified TNAP at Vashon Terminal
- SR 520 Test Pile project



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## Questions????



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